Available online at www.sciencedirect.com
SCIENCE DIRECT
Computers and Electronics in Agriculture 44 (2004) 161–171
Computers and electronics in agriculture
www.elsevier.com/locate/compag

Application note

A GIS web-based tool for the management of the PGI potato of Galicia

Inés Santé [a], Rafael Crecente [a], David Miranda [a], Juan Touriño [b], Fernando Canzobre [b], Ramón Doallo [b,*]

[a] *Department of Agricultural and Forestry Engineering, University of Santiago de Compostela, Spain*
[b] *Department of Electronics and Systems, University of A Coruña, Campus de Elviña s/n, A Coruña E-15071, Spain*

Received 3 April 2003; received in revised form 22 January 2004; accepted 18 March 2004

Abstract

Galicia, in north–west Spain, produces a potato crop, specific to the region, which is protected under the Geographical Indication system as the PGI potato. This Note describes a GIS tool to aid management and decision-making in organization of the production of this crop, together with examples of its application in a region characterized by land fragmentation.

Keywords: GIS; Web; Management tool; Geographical indication; Potato crops

1. Introduction

Galicia is an autonomous region of Spain, located in the north–west of the country, with 3476 km^2 of farmland and a population of almost 3 million people. One third of the land is dedicated to agriculture, which is characterized by a high degree of land fragmentation with an average parcel area of 2500 m^2 (Crecente et al., 2002). Potato cultivation is important to the Galician agricultural economy since it represents 15% of the total cultivated area and 17.5% of the agricultural production, contributing an annual income of €62.3 million to the sector in 1999. The Protected Geographical Indication (PGI) (WIPO, 2003) Potato

* Corresponding author. Tel.: +34-981-167000; fax: +34-981-167160.
E-mail address: doallo@udc.es (R. Doallo).

0168-1699/$ – see front matter
doi:10.1016/j.compag.2004.03.004

of Galicia consists of three production zones: A Limia, Terra Cha and Bergantiños, which include 19 municipalities, 496 registered farmers, 1192 parcels and a cultivated area of 724 ha with a production of 3770 metric tons per year. These numbers will increase as two new zones (Lemos and A Mariña) have joined the PGI in 2002. The Regulatory Council (RC) is the control and certification organization that manages, promotes and protects the Geographical Indication. It represents the potato farmers association for the follow-up and improvement of the production quality so that its better management helps to preserve the potato quality standards.

The RC has been using paper maps as support for spatial information, which involve great efforts to relate attribute information (e.g., farmers, productions and yields) to the parcels drawn on paper. This Note addresses the architecture and functionalities of a GIS tool and its web implementation to manage the PGI Potato of Galicia. It draws on previous experiences of our research group in the development of GIS applications to aid land consolidation projects (Touriño et al., 2001, 2003). The initial objective of the PGI Regulatory Council was to have a tool to aid parcel registration and location tasks. However, in the tool development process it was decided to incorporate advanced capabilities, such as controlling the compliance with the PGI Technical Regulation, or monitoring quality control parameters. On the one hand, the tool allows the integration, maintenance and validation of alphanumeric and cartographic information received from different sources by the RC during every season. It thus facilitates the graphical identification of the parcels cultivated by every potato farmer in a certain season, as required by the PGI Technical Regulation. On the other hand, the spatial analysis of this information makes the tool a decision support system for the RC and potato farmers regarding issues, such as phytosanitary treatments, fertilizers or irrigation management. It also allows a detailed follow-up of quality control indicators of the potato production chain, from the parcel level to the sale in the market. An additional advantage is the speeding up of administrative steps as the tool provides the means to create queries and reports about farmers, parcel characteristics, evolution of production factors. Moreover, the web implementation provides these functionalities to farmers and sector companies, not necessarily skilled in GIS, that cannot afford complex and expensive GIS. This tool is, therefore, a strategic instrument to develop crop management plans, as well as to know and control the potato production, the number of parcels, the cultivated area and its location, as will be required by the European Union in a future establishment of a European potato Market Common Organization.

The International Potato Center in Lima, Peru, has developed an application, DIVA-GIS (Hijmans et al., 2001), focused on plant cultivation (analysis of spatial, ecological and genetic patterns of potato variety distribution), but not on crop management and monitoring. In addition, Hijmans (1997) has proposed GIS-linked simulation models to study the effect of yield-limiting factors on potato production, and to compare different varieties in order to guide crop improvement efforts. The coordinated use of GIS, GPS and simulation models has been applied by Olteanu and Dudui (1997) to monitor agricultural resources and manage potato crops in a precision farming approach. This tool and DIVA-GIS are not web-based applications. Jensen et al. (2000) have designed a web-based decision support system that supplies farmers with real-time information and technical advice for crop management, but it does not take advantage of GIS potential for the spatial analysis of these data.

2. System design

2.1. Architecture

The development of the tool consisted of three phases: database design, GIS customization, and GIS-webserver integration. Fig. 1 shows a schematic overview of the system.

The conceptual design of the database was based on the Entity-Relation model, after consultations with officials of the RC. The subsequent design adapted the conceptual scheme to tables and normal forms of the Relational Data Model (Date, 2000), which helped to debug

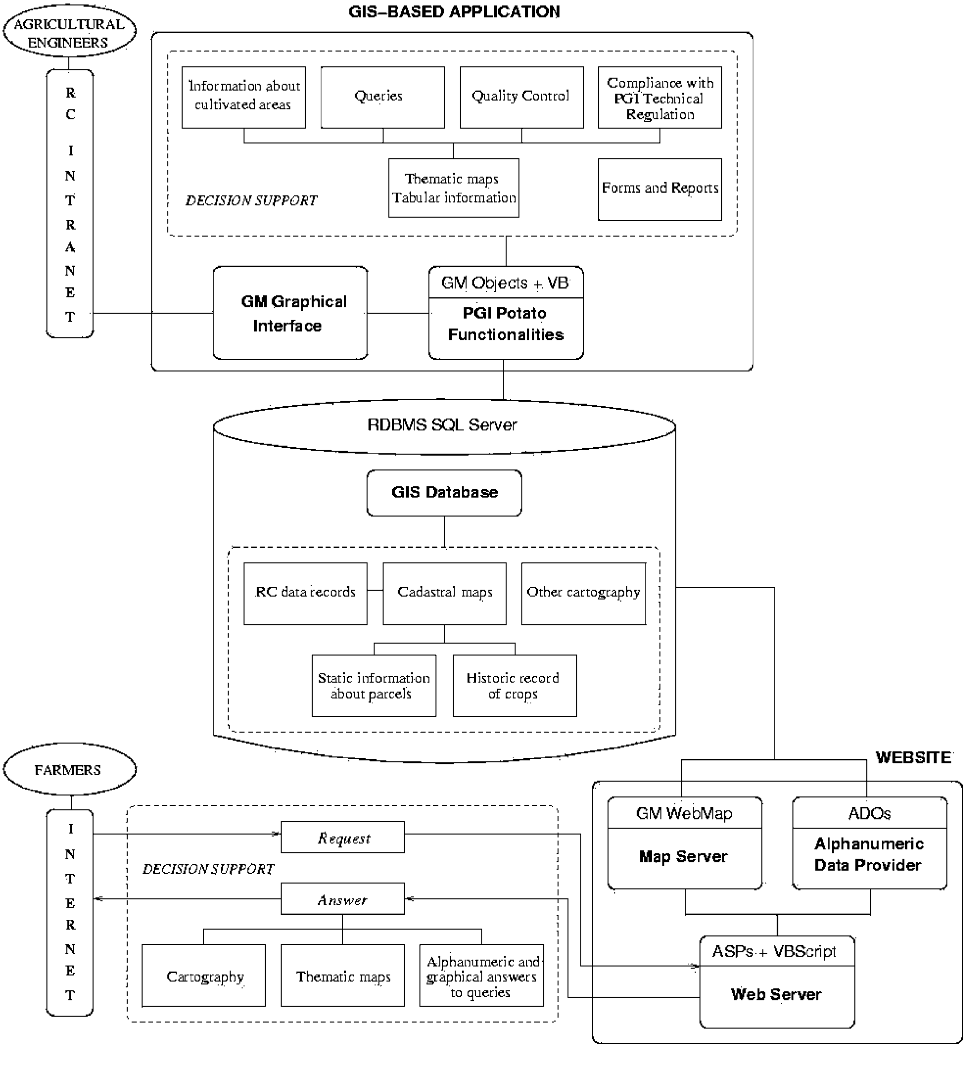

Fig. 1. Tool architecture.

design errors. SQL Server was the RDBMS chosen for the management and integration of the input data. The database is fed by both geographical and alphanumeric data from different sources and formats. The geographical information mainly consists of digital cartography provided by the Galician Government (scales 1:2000 and 1:5000). Moreover, it has been necessary to digitize soil maps available only in paper format. Much effort was needed to validate the cartography. Alphanumeric data include administrative information from the unstructured files of the RC, field data collection in the parcels, results of quality control samples, lists of market prices, etc.

We customized a GIS package in an intranet environment to meet the needs of the RC. In particular, our tool is embedded in GeoMedia Professional® (Intergraph Corp., 2002a), and the new functionalities (see Section 2.2) were implemented as software components built on top of GeoMedia (GM) and presented as commands through graphical interfaces. The components were developed using Microsoft's ActiveX/COM (Component Object Modelling) technology and Visual Basic (VB) as programming language. GeoMedia provides a flexible integration with VB, as well as objects with methods and properties directly accessed from VB through the Geomedia Automation Objects Model. This makes it possible to carry out in a single step operations that require multiple steps in a standard GIS (e.g., generation of thematic maps based on complex queries). Moreover, many functionalities of the tool cannot be reproduced using the standard commands of the GIS.

The next stage was to include the new GIS functionalities in a restricted access website (Santé, 2001). The web pages are generated dynamically on the server side by retrieval of appropriate information from the constantly updated database. The website was built with HTML pages, Active Server Pages (ASPs) and Visual Basic Script (VBScript). We have used Internet Information Server as web server together with GeoMedia WebMap® (Intergraph Corp., 2002b) as map web server.

The answers to the queries can be alphanumeric information (usually in a tabular format) or maps. The code that allows execution of the alphanumeric and map queries is in the ASP files. These are text files that contain HTML labels with embedded VBScript code and references to ASP objects. The VBScript lines are executed on the web server when the files are invoked, generating a map or a table that is inserted as an object in an HTML page, which is sent to the browser that requested it. If the user selects a map display, the ASP file execution invokes Geomedia WebMap objects, the map is generated and then inserted as an object in the HTML page. WebMap provides objects to the ASPs and VBScript to execute a large variety of actions, such as obtaining the geometry of map entities, displaying raster images, controlling the visualization format, or programming the map actions. If the user selects alphanumeric information, then the ASP file is connected to the database through ActiveX Data Objects (ADOs), and builds an HTML page containing a table with the required information.

The georeferenced thematic information supplied by the website is based on municipal maps. Maps are not images, but interactive objects in Active Computer Graphics Metafile (ACGM) format to select the data needed within the geographical context displayed in each map. Thus, programmed actions (e.g., the execution of an SQL query) can be launched by clicking on an entity of the ACGM map. For instance, the map shown in Fig. 2 was obtained by querying about the parcels cultivated in a certain season. It

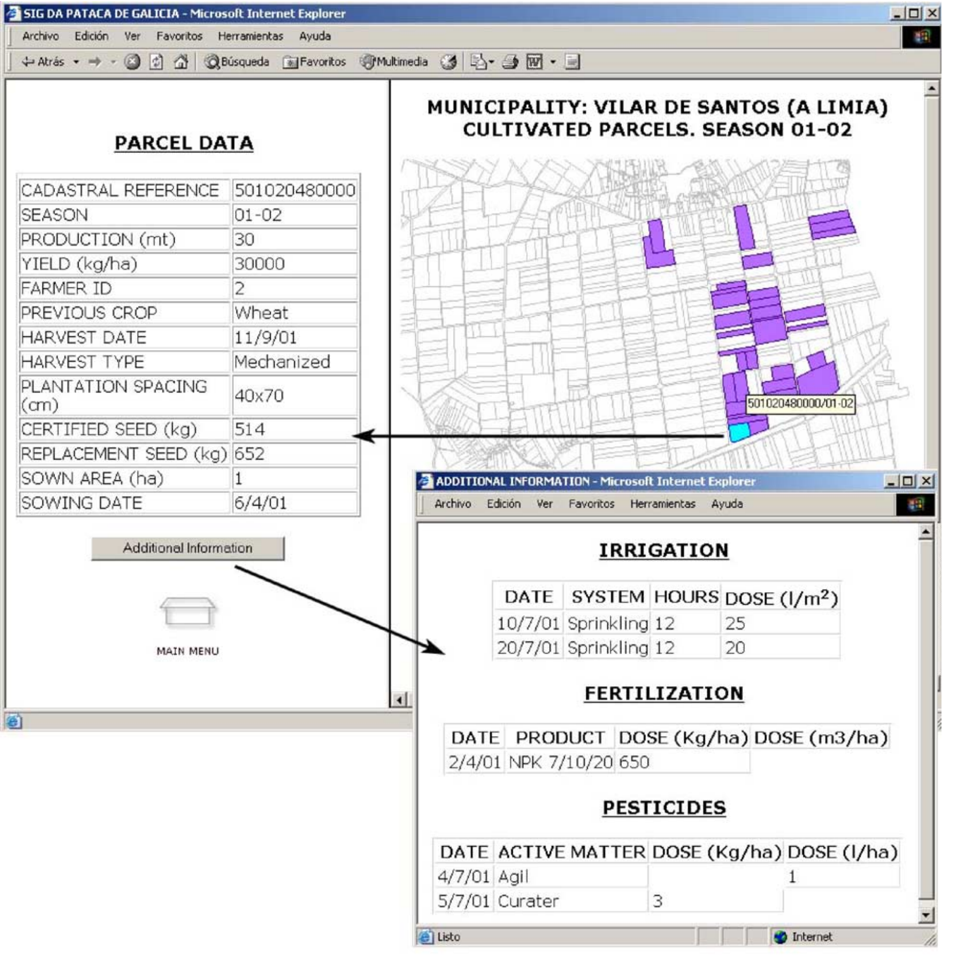

Fig. 2. Screenshot of the PGI website (translated into English).

is a clickable map so that when clicking on a parcel, it shows a table with its relevant crop parameters for the specified season, as well as additional information about treatment and irrigation practices used. This tabular information is generated by supplying the parcel code (obtained through a WebMap object when clicking on the parcel) as a parameter of the corresponding SQL instruction in an ADO connection. A similar mechanism is used to navigate through the maps: when clicking on a map entity its code is obtained from the database and an ASP file is executed to generate the new map by introducing that code as a parameter in the query that selects the entities that will be displayed in the map.

2.2. Tool functionalities

The tool's scope embraces the customized GIS, intended for the PGI management by the Regulatory Council, and the website, whose function is to provide farmers with direct access to the information gathered by the RC and allow them to make queries in order to support strategic crop-related decision making.

The most relevant functionalities demanded by the RC were embedded in the GIS to guide decision processes oriented to improve the potato crop quality and yield:

- Straightforward generation of different kinds of personalized thematic maps, such as soil maps (pH, organic matter, Ca, Na, K, P and Mg), potato production and yield maps, maps of plantation spacing, amount of certified and replacement seed, irrigation areas (including irrigation quantity, frequency and method), doses of fertilizers and pesticides.
- Commands for searching and displaying parcels following different criteria (by season, farmer, cadastral code, etc.), and also obtaining tabular attribute information of selected parcels.
- Maps and tabular information of variables measured in quality control samples taken (depending on the indicator) in the parcels, warehouses, in the packaging process and in supermarkets. Examples of these quality control variables are percentage of dry matter, reducing sugars, starch and residues, nitrate and nitrite content, incidence of potato diseases (common scab, silver scurf, Rhizoctonia canker).
- Automatic identification of parcels that do not observe the PGI technical norms, in order to allow the RC to control the compliance with the quality rules. Examples of these rules are that a parcel must not have potato crops in two successive seasons, yield must be less than 35 t/ha for irrigated land and 22 t/ha for dry land production, potato diameter must be between 40 and 80 mm, potatoes with residues less than 2%, rotten potatoes less than 1%.
- Specific interfaces for information management, as well as generation of customized reports, forms and statistics (displayed or printed).

The website includes specific information about the PGI Potato of Galicia and its RC; for instance, functions of the Council, Technical Regulation of the Indication, properties of the Kennebec potato variety adopted by the PGI, etc. GIS-based functionalities are provided through clickable maps. There is a base map of the regional district division from which municipalities can be accessed. The thematic maps about potato cultivation described previously can be obtained at both levels (regional and municipal), including representative parameters, such as relative coverages (percentage of potato cultivated area with respect to other crops or with respect to the total area). Additional thematic maps useful for agricultural production and, particularly, for potato cultivation are also provided. Thus, available cartography includes different layers of information that can be combined to generate customized maps: geology, hydrology, aspect, slope, quality and fragility of the landscape, road network, built areas and spatial planning categories. From the municipal map it is also possible to perform several kinds of map queries, such as cultivated parcels by season and/or farmer (including associated tabular information), as well as to obtain crop information at parcel level, as shown in the example of Fig. 2.

3. System evaluation

The municipality of Vilar de Santos was chosen as case study to evaluate the tool as it has a reasonable size for testing purposes. It is a small municipality with 940 ha of farmland of which 54 ha, distributed among 48 parcels and 23 farmers, are devoted to PGI potato production. Once the tool was introduced in the RC only half a day was needed to train the staff (mainly agricultural engineers) in the use of the tool. The information of Vilar de Santos collected in sowing declarations and field reports during the 2001–2002 season was entered into the GIS database. This automatically allowed the straightforward publication of this information in the associated website. The farmers in this municipality were informed that this website was made available and they were asked to consult it for its subsequent evaluation. Next, a workhop was held with the participation of tool developers, RC experts and a group of representative farmers from Vilar de Santos, for the analysis and discussion of the results and experiences gained from the tool. The workshop consisted of two sessions: contributions of the tool to satisfying the management needs of the RC, and evaluation of the services offered to farmers. In each session a number of deficiencies were identified, which led to further adjustments in the tool that involved the inclusion of additional functionalities, described in the next subsections.

3.1. Evaluation by the Regulatory Council

The RC technicians valued positively the contribution of the tool to a faster and more efficient management of the large amount of information handled by the RC, to a better production quality control, and to an easier follow-up of the evolution of the cultivated area and parcels. They were asked to record the time spent in the associated day-to-day tasks with the purpose of evaluating the performance of the tool as compared to the traditional procedure. As can be observed in Table 1, the work involved in entering the information into the database is compensated by the significant reduction in time and effort required for managing the information throughout the entire season. The tool was proved to be particularly useful to control compliance with the PGI technical norms, and production quality standards. However, the technicians emphasized the need for speeding up the administrative procedure, since between June and July the farmers have to go to the RC headquarters to provide the information and documents required by this organization. This increases the workload of the technicians, as well as the loss of time for the farmers in slow bureaucratic processes. Moreover, it could also be verified that entering the information into the system from paper forms supplied by the farmers required a considerable time investment. These two facts led to consideration of the possibility that farmers could supply the information required by the RC through the website. It was first considered that the farmers themselves entered the information into the system's database using web forms. However, it was finally decided to store this information in a temporal database (with the same structure as the main database) as the RC technicians warned about the frequent flaws and errors in the information provided by the farmers, in addition to the appearance of new errors linked to the use of a new technology not well-known by the farmers. This way, the information can be easily reviewed and edited by the technicians before consolidating it in the main database of the GIS tool. This functionality was incorporated in an independent section of

Table 1
Analysis of the GIS tool performance in the management and analysis of information in Vilar de Santos

Task	Time required	
	Before implementing the tool	After implementing the tool
Information input (from paper forms)	–	2 h 30 min
Identification and location of the parcels based on one or several attributes	10–30 min	5 min
Simple queries: cultivated area, hours of irrigation, doses of fertilizers, etc.	10–30 min	5 min
Identification and location of the parcels whose production does not comply with the quality standards	≅1 h, 30 min	5 min
Identification and location of the parcels that do not comply with the PGI technical norms	≅1 h	5 min
Spatial representation of the information derived from quality control	–	5 min
Follow-up of the evolution of different factors (i.e. cultivated area, number of parcels, disease incidence, etc.) throughout several seasons	≅1 h–2 h/factor	15 min (cultivated area) 10 min (number of parcels) 20 min (disease incidence)
Generation of location maps, thematic maps, etc.	–	5–20 min
Generation of reports	30 min/report (on average)	Immediate

the website, which has 3 web forms that let the registered PGI farmers send via web the sowing declarations, registrations of plantations, and registrations of packing plants and warehouses required by the RC every season.

3.2. Evaluation by the farmers

The farmers showed their satisfaction with the possibility of consulting the information gathered by the RC, which was previously only available to technicians. All the farmers in Vilar de Santos responded positively to the questions: is the website user-friendly?, and does the website provide useful information for making decisions about crop management? However, they made a number of suggestions aimed at improving the website. Sometimes the potato cultivated parcels do not match up with the cadastral parcels because the farmers do not dedicate the entire parcel to potato cultivation, or because several cadastral parcels are managed as a single unit. This caused confusion among the farmers when it came to recognizing their parcels in the cadastral maps. This drawback was overcome by adding to the GIS a new layer of information named ‘agricultural parcels’ to visualize the borders of the areas actually planted to potatoes. The geometry of this layer is digitized by the RC experts each season, starting with the parcels from the cadastral property register, and modifying them to represent the areas dedicated to potatoes. An option for visualizing this layer of information was included in the website.

Another complaint shared by most farmers was the long waiting time for visualizing the cadastral maps. This happened because high-speed Internet connection is not yet available in most rural areas of Galicia. Thus, in order to overcome the slow visualization of the parcel maps, an addition to the website included the option of visualizing only the potato cultivated parcels to avoid to download the whole cadastral map. Finally, a utility that the farmers missed in the website was a 'management recommendations' section for the current season. This option, which was left pending for future collaborative works with the RC, would require the development of techniques and crop management models based on the historical information registered by the system.

4. Operational experience

The implementation of this tool involved a considerable expense to the RC, both economic (hardware and software), and of organization and adaptation to the working system required by the tool. The initial testing of the tool has demonstrated that this expense is compensated by the reduction of the time used by the technicians in the information management and analysis, by making the production quality control easier, and by improving the services offered to the associated farmers. Among these services are visualizing and consulting the information gathered by the RC each season, obtaining maps of the area, and the management of administrative processes of the farmers with the RC via web (accomplishment of sowing declarations, registration of plantations, packing plants and warehouses). The website was proved to be a good way to divulge just-in-time information from the RC to the geographically scattered farmers and related companies, as well as to researchers and technical personnel in the sector. For instance, tool users could check the effect of different pesticide doses on the disease impact registered in the parcel production, or evaluate the yield increase depending on the method and frequency of irrigation.

The farmers in this area are of an older age, and are not familiar with the use of web technologies. Therefore, it has been necessary to provide information about the possibilities of this new technology, and to train the farmers offering courses in which the use of the website is explained. The simplicity and friendliness of the website let the farmers in Vilar de Santos to understand and use the application in a single training session. It is expected that the active involvement and commitment of the farmers will continue to play a key role in its success.

5. Projected further developments

As this is a continuously evolving application, an open research line is to incorporate prediction models for crop production and yield, based on the historical GIS information of different seasons. GIS would provide maps with seasonal crop delineation and information on management practices that could be used as input data by the crop simulation model. The model would in turn allow to guide crop improvement efforts by analysing the spatial patterns of simulated yields and studying the yield limiting factors. The results obtained with this GIS-linked simulation model would serve as basis for including in the website a ‘management recommendations’ section aimed towards advising the farmers about the most appropriate cultivation techniques and practices.

6. Conclusions

Experience so far with this tool has demonstrated that it is capable of meeting the diverse needs of farmers, agronomists and regional government agencies. On the one hand, the analysis of the workload reduction of the RC technicians has shown the effectiveness of GIS technology in the management of an agricultural cultivation in which associations of farmers are involved. Therefore, the tool architecture presented here could also be applied to other agricultural organizations in order to manage the information and the quality standards compliance of the crops. It would imply corresponding changes in the data modules of Fig. 1, but the tool design facilitates the reuse of the functional software components of the architecture with minor changes. This architecture also provides the basis for the projected lines of development. On the other hand, interviews made with the participants in the workshop indicated that the web-based application had a good acceptance by the farmers. It was considered a friendly way to access and query information which can be used as decision support for planning different aspects of potato cultivation, such as site selection, irrigation system design, or fight against diseases. Moreover, regional government agencies like the Institute of Agriculture of the Ourense province (Galicia, Spain), or the Galician Agricultural Extension Service have also become beneficiaries of this GIS web service. They are aware of the potential applications of the valuable information disseminated through the website in their research and educational programs related to potato production (e.g. fertilization recommendations, advice about crop profitability, etc.).

Acknowledgements

This work was funded by the Galician Government (Xunta de Galicia) under Contract PGIDIT03SIN10501PR and by the Regulatory Council of the PGI Potato of Galicia. We thank the Editor-in-Chief Sidney Cox for his helpful comments to improve the paper.

References

Crecente, R., Alvarez, C., Fra, U., 2002. Economic, social and environmental impact of land consolidation in Galicia. Land Use Policy 19, 135–147.

Date, C.J., 2000. An Introduction to Database Systems. Addison-Wesley, Reading, MA.

Hijmans, R.J., 1997. Simulation models for studying limiting factors in potato production. In: Denisov, N., Heberlein, C., Czaran, L., Simonett, O. (Eds.), GIS in Agricultural Research: Awareness Package. UNEP/DEIA/TR.97-9 (Case study #38).

Hijmans, R.J., Guarino, L., Cruz, M., Rojas, E., 2001. Computer tools for spatial analysis of plant genetic resources data. Part 1. DIVA-GIS. Plant Genetic Resources Newsletter 127, 15–19.

Intergraph Corp., 2002a. Geomedia Professional: Developer Documentation, Release 5.0. Intergraph Corp., Huntsville, AL.

Intergraph Corp., 2002b. Geomedia WebMap: Developer Documentation, Release 5.0. Intergraph Corp., Huntsville, AL.

Jensen, A.L., Boll, P.S., Thysen, I., Pathak, B.K., 2000. Pl@nteInfo—a web-based system for personalised decision support in crop management. Computers and Electronics in Agriculture 25, 271–293.

Olteanu, G., Dudui, S., 1997. Using GIS for monitoring of agricultural resources and integrated potato crop management. In: Proceedings of the 12th ESRI European User Conference, Copenhagen, Denmark. ESRI, Redlands, CA.

Santé, I., 2001. GIS and Web Technologies for Rural Engineering. Master's thesis. Department of Agricultural and Forestry Engineering, University of Santiago de Compostela, Spain, 734 pp. (in Spanish).

Touriño, J., Rivera, F.F., Álvarez, C., Dans, C.M., Parapar, J., Doallo, R., Boullón, M., Bruguera, J.D., Crecente, R., González, X.P., 2001. COPA: a GIS-based tool for land consolidation projects. In: Aref, W.G. (Ed.), Proceedings of the Ninth ACM International Symposium on Advances in Geographic Information Systems, Atlanta, GA. ACM Press, New York, pp. 53–58.

Touriño, J., Parapar, J., Doallo, R., Rivera, F.F., Boullón, M., Bruguera, J.D., González, X.P., Crecente, R., Álvarez, C., 2003. A GIS-embedded system to support land consolidation plans in Galicia. International Journal of Geographical Information Science 17, 377–396.

World Intellectual Property Organization (WIPO), 2003. What is a Geographical Indication? (http://www.wipo.org/about-ip/en/about geographical ind.html).